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Coupling coordination relationship between forestry industry development and the ecological environment: evidence from the Northeast region of China

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The Chinese economy is entering a new era of high-quality development, and promoting high-quality development has become an inevitable requirement for maintaining healthy economic development and adhering to the laws of economic development. As an essential component of China's modern economic construction, the high-quality development of the forestry industry will serve as a meaningful way to transform traditional and emerging driving forces and accelerate the construction of ecological civilization. However, as the development of the forestry industry mainly relies on forest resources, the continuous consumption of these resources will inevitably impact the environment, leading to contradictions between the industry's development and ecological preservation. Therefore, taking the Northeast region as an example, this paper applies the coupling coordination degree model to calculate the coupling coordination relationship between the development of the forestry industry and the ecological environment in Northeast China from 2011 to 2022. This analysis holds important practical significance for promoting coordination between the development of the forestry industry and the ecological environment in the region. The results indicate that, first, the development of the forestry industry and the ecological environment promote, influence, and constrain each other. Second, from 2011 to 2022, there is still a specific gap between the development of the forestry industry and the ecological environment in Northeast China, although both have reached a state of benign coordination. Third, during this period, only Liaoning Province exhibited a relationship between the development of the forestry industry and the ecological environment that included antagonism, adaptation, coupling, and imbalance, while the other two provinces showed no signs of imbalance. Based on the above findings, the Northeast region can promote the coupling coordinated development of the forestry industry and the ecological environment by restructuring the forestry industry transformation model, rationally developing and utilizing forest resources, advocating for clean production projects, and promoting low-carbon economic development.

KEYWORDS

forestry industry development, ecological environment, coupling coordination, low-carbon economy, comprehensive index method

1 Introduction

The ecological environment has become a key factor for countries in achieving sustainable development goals (Zhang et al., 2024). The carbon sequestration capacity of ecosystems also enhances global carbon neutrality efforts (Du et al., 2024) and remains a primary issue to be addressed in future national environmental planning (Liu et al., 2017). Population factors (Luo et al., 2025), urbanization (Liu et al., 2024), and the development of various industries all impact the ecological environment. With the increasingly prominent global environmental problems, forestry will play an irreplaceable role in promoting ecological environment construction in multiple countries. China's forestry construction has gradually shifted toward focusing on environmental development. As an important economic sector, forestry contributes to China's economic development. It is the cornerstone of ecological civilization construction, becoming an essential component and main direction for promoting high-quality regional economic development. However, with the rapid economic development and society's continuous progress, human demand for forestry has become more diverse. Meanwhile, forestry development has specific monetary value and can optimize and improve the ecological environment. Currently, the forestry industry alone cannot meet society's demand for an enhanced quality of life by producing goods and services (Dong et al., 2013).

The coupling coordination between the development of the forestry industry and the ecological environment refer to the fact that the development of the forestry industry can improve the ecological environment and promote ecological balance. At the same time, with the rapid development of the forestry industry and the continuous development and utilization of forest resources, the structure of the forestry industry is constantly changing. The aggregation of industrial scale leads to intensified pollution emissions, reduced recoverable resources, increased demand for the ecological environment in forestry industry development, and the decline of environmental service functions of the ecological environment, resulting in changes in the ecological environment. The PSR model can explain the relationship and interaction between the forestry industry development and the ecological environment. The PSR model consists of three types of indicators: Pressure, State and Response.

The PSR theoretical model, proposed by Canadian statisticians David J. Rapport and Tony Friend (Zeinab et al., 2019), offers a comprehensive framework for understanding the relationship between the forestry industry and the ecological environment. The growth of the forestry industry enhances economic benefits and serves as a crucial economic resource for forested regions. Concurrently, it can improve the ecological environment and foster ecological balance. However, as the forestry industry expands, it inevitably exerts pressure on forest ecological resources, which can subsequently hinder its development. Therefore, it is essential for future forestry initiatives in China to strive for a harmonious balance between industry growth and natural ecosystems, thereby promoting the coordinated and sustainable development of both the forestry sector and the ecological environment. A scientific understanding of the interactions between these two areas—analyzing the impact of the forestry industry on the environmental climate and clarifying how the ecological environment constrains or supports the industry's growth—will facilitate the maximization of forestry's comprehensive benefits and aid in uncovering the diverse values of the forestry industry.

The rapid development of the world economy mostly comes at the cost of ecological damage, which will lead to a series of environmental problems (Ha et al., 2022). There is an inevitable correlation between the economy and the ecological environment (Costanza, 1989). Forests' multifunctionality makes them versatile. The most common conflict is between wood production and forest resource cultivation and protection (Gustafsson et al., 2012). Due to agricultural development, excessive exploitation, and wars, natural forest resources have significantly decreased, leading to the problem of prioritizing the economy over the environment in China's forest management (Liu et al., 2011). Environmental pollution and ecological degradation have broken geographical limitations and become common global issues. The environmental, financial, and social systems of forestry show an unstable development trend, whereas the forest system itself shows a positive development trend (Chen and Ji, 2017). Healthy and sustainable coordinated development between the economic system and the ecosystem will be conducive to achieving a win–win situation for both systems (Glen et al., 2007). Bennett and Kruger (2013) elaborated on South Africa's environmental policies in areas such as forests, hydrology, and biodiversity management from the perspectives of forestry and ecology. Implementing ecologically intensive management policies can also effectively promote the development of forestry (Montesinos, 2019); green finance policies will also effectively promote the achievement of sustainable development goals (Xu et al., 2025) and better guide forestry production practices (Blanco et al., 2022). Fuwape (2003) examined the environmental pollution resulting from wood processing and utilization and operations within the forest industry and explored effective strategies for mitigating this pollution. Michelsen et al. (2008) assert that forestry activities significantly affect the environment. They note that different types of forestry activities exert varying levels of impact, and a specific relationship exists between these activities and their environmental effects.

Many scholars have proposed different methods for analyzing the coupling coordination relationship between systems. Most scholars choose the comprehensive index evaluation method (Wei and Zimmermann, 2017), economic evaluation method (Su et al., 2019), DAHP–TOPSIS improvement method (Liu and Wang, 2018), variable fuzzy evaluation method (Lv et al., 2023), ecological environment monitoring (He et al., 2025), and ecological footprint rating method (Xi et al., 2010; Wang et al., 2024) when evaluating the relationship between systems. Most scholars in the forestry and ecological environment study use the environmental Kuznets curve and spatial econometric models to analyze the relationship between the two quantitatively and qualitatively analyze the mechanism of their interaction (Zhang et al., 2020).

The Northeast region is located in northeastern China and includes three provincial-level administrative regions: Liaoning Province, Jilin Province, and Heilongjiang Province. It has a vast territory and abundant forest resources, with forest stock accounting for approximately one-third of the national total. It is home to critical national ecological functional areas such as the Great Xing'an Mountains and Changbai Mountains, a vital forest distribution area, and a production base for China's grain, soybeans, and livestock. It also makes it a critical carbon sink base and a sensitive area for addressing environmental issues in China. In 1995, timber production in the region accounted for 38.4% of the national total.

Additionally, with its abundant mineral, oil, coal, and water resources, the northeast region of China plays a significant role in protecting water sources, regulating climate, preserving biodiversity, maintaining ecological balance, and safeguarding national environmental security. It serves as an essential ecological barrier in northern China. The agriculture and forestry in the northeast region of China are relatively developed, forming a relatively developed agricultural and forestry industry system and a complete ecological system with prominent regional and pattern characteristics. It provides a natural foundation for comprehensive, large-scale agrarian bases. The northeast region of China has rich and diverse resources. They have played a vital role in the country's economic construction, especially in the early years of the People's Republic of China, making a historic and outstanding contribution to capital accumulation. However, due to resource depletion, a relatively single industrial structure, severe environmental pollution, and the impact of the planned economic system, the Northeast region of China has gradually declined, with low efficiency in economic development and social progress. It will further highlight the contradiction and problems between financial development and the ecological environment.

To better address the conflict between the two, the northeast region has implemented various measures to gradually foster economic recovery while promoting both sectors' coordinated and sustainable development, all without compromising the ecological environment. In 2023, Xi Jinping presided over a symposium on promoting comprehensive revitalization in the new era in Northeast China, emphasizing the importance of recognizing the region's significant mission and striving to write a new chapter in its revitalization. By promoting high-quality development through innovation-driven strategies and utilizing high-level innovation, the northeast region of China can effectively promote economic recovery, achieve sustainable resource restoration, promote social stability and development, and thereby promote coordinated and integrated development of economy, ecology, resources, and society.

Therefore, the northeast region of China holds a unique position in balancing economic development with environmental conservation. By calculating the coupling coordination relationship in the northeast region of China, we can understand the current relationship and effectively relieve the conflicts between the development of the forestry industry and the ecological environment, thereby stimulating high-quality regional economic development. This article establishes a pragmatic foundation for the future advancement of forestry in the northeast region of China, serving as a valuable point of reference for other forestry regions or nations. Thus, calculating the coupling coordination between the development of the forestry industry and the ecological environment in Northeast China and determining their interdependent relationship holds immense practical significance.

The unique characteristics of the northeast region of China make it an innovative choice as the focus of this study. The Northeast region of China has obvious resource advantages, especially abundant forest resources. However, resources are limited to the diverse needs of humanity. At the same time, excessive consumption of resources to achieve economic benefits will also lead to serious environmental issues, and some economic value will be lost while protecting the environment. The economy, ecology, and resources exist in a state of mutual promotion, influence, and constraint. Therefore, this article takes the northeast region of China as an example to explore the coupling relationship between forestry economics and the ecological environment, which has particular value and specificity. The contradiction between economic development and ecology has always existed, but the forestry industry has both economic and ecological benefits. Some scholars may choose positive indicators when calculating the relationship between the two, ignoring the potential damage to the ecological environment caused by excessive resource consumption and the pursuit of economic development. Therefore, this article uses negative indicators when calculating the relationship between the two.

The article first elaborates on the regional, representative, and unique characteristics of the research area, highlighting the practical significance of selecting Northeast China as the focus of this study. Second, by applying the coupling coordination model, it enables a comprehensive analysis of the interaction between the development of the forestry industry and the ecological environment in the northeast region of China. Finally, based on the existing state of forestry industry development and the outcomes of the coupling coordination analysis, the article offers a coherent explanation of the intricate relationship between forestry industry development and the ecological environment. At the same time, it proposes feasible suggestions to promote coordinated development between the two and high-quality, low-carbon economic growth.

2 Materials and methodology

2.1 Research methods

2.1.1 Comprehensive index method

The comprehensive index method is a widely used calculation method that quantitatively explains the effects and degrees of changes in complex things or phenomena. By quantifying the indicator values that describe things or phenomena, each indicator can be reflected under equal conditions. The weight value of each indicator is determined through corresponding methods, and finally, its comprehensive evaluation value is calculated.

First, select the target sequence x_0 is selected. According to the direction of the chosen indicator, if the indicator is positive, a higher value indicates better performance. The target sequence selected is the maximum value of each indicator. If the indicator is negative, a lower value indicates better performance; the chosen target sequence is the minimum value of each indicator. This is shown in Equation 1.

$$x_0 = \{x_0(1), x_0(2), \cdots x_0(n)\}. \tag{1}$$

Second, the initialization matrix is determined. The attribute matrix is formed between the solution set and the sequence, and initialization is performed on the attribute matrix to obtain the initialization matrix Y.

Third, the judgment coefficient is calculated. The gray correlation degree judgment coefficient is computed using the initialization matrix, as shown in Equation 2.

$$\xi_i(k) = \frac{\min_i \min_k |x_0(k) - x_i(k)| + \zeta \max_i \max_k |x_0(k) - x_i(k)|}{|x_0(k) - x_i(k)| + \zeta \max_i \max_k |x_0(k) - x_i(k)|}$$
$$\zeta = 0.5. \tag{2}$$

Fourth, weights are determined. According to the gray correlation degree judgment coefficient, the mean value of each indicator is determined, forming a matrix w. This matrix can reflect the proportion of each indicator in the entire indicator set. The matrix w is normalized to form W, which is the weight.

Finally, the comprehensive evaluation value is calculated, as shown in Equation 3.

$$Y_j = \sum_{i=1}^{n} X_{ij} \times W_i. \tag{3}$$

Here, Y_j is the comprehensive evaluation value for year j. X_{ij} is the statistical value of indicator i in year j. W_i is the weight of indicator i. n is the number of evaluation indicators.

2.1.2 Coupling coordination model

The coupling coordination model is a tool and method for measuring the interaction and coordination degree between various elements, quantifying the interaction between each component, and calculating their coordination degree. It is a highly effective instrument for studying the relationships between composite systems such as economic development, environment, resources, and society; it is expressed as shown in Equations 4–6.

$$D = \sqrt{C \times T}, \tag{4}$$

$$C = n \times \left[\frac{U_1 U_2 \cdots U_n}{(U_1 + U_2 + \cdots + U_n)^n}\right]^{\frac{1}{n}}, \tag{5}$$

$$T = \alpha K_\omega + \beta H_\omega. \tag{6}$$

Here, D refers to the coupling coordination degree, C indicates the coupling degree, and T refers to coordination. K_ω and H_ω reflect the comprehensive evaluation values of the two systems. α and β are the weights of the two systems. Due to the two systems' equal importance, each weight accounts for half. D represents the degree of coupling coordination—the higher the value, the greater the level of coupling coordination. Conversely, a lower value indicates a weaker degree of coordination. According to the coupling coordination model, the value of D allows for classification into 10 levels and five categories, as provided in Table 1.

2.2 Study area and data sources

This article focuses on the northeastern region of China. It includes three provincial-level administrative regions: Liaoning Province, Jilin Province, and Heilongjiang Province. The Northeast region of China has a high forest coverage rate, with forest stock accounting for approximately one-third of the national total. It is also rich in oil, coal, minerals, and water resources. The region is rich in resources and has an excellent ecological environment, which plays an undeniable role in maintaining environmental balance, windbreak and sand fixation, biodiversity, climate regulation, carbon sequestration, and oxygen release. It serves as an essential ecological barrier in northern China. Both agriculture and forestry are relatively well-developed, and the region has formed a basic pattern of agricultural systems and regional differentiation, serving as a natural foundation for comprehensive, large-scale agrarian bases.

The northeast region of China is not only resource-rich but also had an early start in economic development, making significant historical contributions to the growth and development of New China. However, the outstanding contribution of the northeast region to China's economic development has led to excessive resource consumption. Long-term resource consumption can damage the ecological environment and require a more extended restoration period, leading to resource crises and economic difficulties. The resource predicament also poses obstacles to the economic development of the northeast region of China, hindering economic growth and the efficiency of social progress, ultimately leading to contradictions between the economy and the environment.

Heilongjiang and Jilin provinces, which are included in the northeast region, have key state-owned forest areas with particularly abundant natural forest resources, making the region more dependent on forest resources, while Liaoning Province represents collective forests. They reflect the complex economic and ecological relationships from perspectives of different ownership structures. Therefore, selecting the northeast region of China as the research subject has a certain representativeness and uniqueness. The map of the northeast region of China is shown in Figure 1.

According to the *China Forestry Statistical Yearbook*, the *China Forestry and Grassland Statistical Yearbook*, and the Statistical Yearbooks for three provinces—Heilongjiang Province, Jilin Province, and Liaoning Province—from 2011 to 2022, relevant indicator values related to forestry industry development and the ecological environment in northeast region of China were collected. However, due to the absence of some indicators, this article uses the mean method to fill in the missing data. The data are provided in Tables 2 and 3.

TABLE 1 Coupling coordination level classification.

D	Coupling coordination degree	Coordination level	Coupling coordination stage
D∈(0.0~0.1)	Extreme imbalance	1	Imbalanced
D∈[0.1~0.2)	Severe imbalance	2	
D∈[0.2~0.3)	Moderate imbalance	3	Antagonistic
D∈[0.3~0.4)	Mild imbalance	4	
D∈[0.4~0.5)	Near imbalance	5	Running in
D∈[0.5~0.6)	Barely coordinated	6	
D∈[0.6~0.7)	Primary coordination	7	Coupled
D∈[0.7~0.8)	Intermediate coordination	8	
D∈[0.8~0.9)	Good coordination	9	Coordinated
D∈[0.9~1.0)	High-quality coordination	10	

FIGURE 1
Map of the northeast region of China.

TABLE 2 Indicator values of forestry industry development in the northeast region of China from 2011 to 2022.

Time	Forestry industry structure											
	Proportion of the forestry primary industry			Proportion of the forestry secondary industry			Proportion of the forestry tertiary industry			Ratio of the total forestry output value to GDP		
	Heilongjiang Province	Jilin Province	Liaoning Province	Heilongjiang Province	Jilin Province	Liaoning Province	Heilongjiang Province	Jilin Province	Liaoning Province	Heilongjiang Province	Jilin Province	Liaoning Province
2011	40.47	27.78	27.78	46.01	60.67	60.67	13.52	11.55	11.55	9.23	13.27	7.57
2012	40.15	27.08	55.13	45.42	60.86	31.39	14.43	12.05	13.48	9.93	13.26	8.67
2013	37.50	26.83	52.24	46.80	61.21	32.35	15.70	11.97	15.41	10.81	14.33	9.05
2014	38.29	26.96	53.1	45.92	61.42	32.59	15.79	11.62	14.31	11.35	14.56	9.16
2015	37.40	25.8	55.13	46.11	60.55	30.09	16.49	13.65	14.78	12.31	15.47	8.24
2016	37.77	25.91	57.65	47.33	60.25	27.04	14.90	13.84	15.31	12.62	15.02	5.74
2017	40.38	26.96	55.89	44.98	57.16	26.91	14.64	15.87	17.2	11.91	13.72	5.29
2018	38.78	26.98	57.65	45.09	55.7	26.4	16.13	17.32	15.94	11.43	12.42	4.67
2019	45.03	29.99	57.61	27.77	50.65	26.79	27.20	19.36	15.6	9.49	9.6	4.08
2020	49.53	36.72	60.77	27.49	45.94	27.12	22.98	17.34	12.1	8.87	6.99	3.5
2021	50.12	33.02	58.56	27.35	45.3	28.13	22.53	21.68	13.31	8.63	7.16	3.14
2022	48.89	32.03	60.25	25.11	43.86	28.32	25.99	24.1	11.43	5.56	7.94	2.38

Time	Forestry investment and economic construction								
	Investment in forestry industry development			Forestry support and guarantee investment amount			Investment in forestry infrastructure construction		
	Heilongjiang Province	Jilin Province	Liaoning Province	Heilongjiang Province	Jilin Province	Liaoning Province	Heilongjiang Province	Jilin Province	Liaoning Province
2011	17,305	41,885	312,425	1,039,119	279,845	66,294	-	-	-
2012	5,247	64,186	13,000	45,921	79,066	68,256	916,943	265,716	23,248
2013	8,658	39,674	53,352	88,295	137,659	25,555	397,123	132,088	14,951
2014	12,437	39,983	342,937	34,022	85,035	39,826	132,519	129,695	12,665
2015	12,198	42,372	29,259	37,020	76,473	35,327	137,879	92,074	5,215
2016	57,291	25,091	24,831	168,063	155,953	58,782	-	-	-

(Continued on following page)

10.3389/fenvs.2025.1604533

TABLE 2 (*Continued*) Indicator values of forestry industry development in the northeast region of China from 2011 to 2022.

Time	Forestry investment and economic construction								
	Investment in forestry industry development			Forestry support and guarantee investment amount			Investment in forestry infrastructure construction		
	Heilongjiang Province	Jilin Province	Liaoning Province	Heilongjiang Province	Jilin Province	Liaoning Province	Heilongjiang Province	Jilin Province	Liaoning Province
2017	86,802	161,290	40,051	163,297	151,172	106,748	121,008	53,522	819
2018	27,064	89,249	25,034	163,834	137,821	128,868	48,539	33,240	1,308
2019	-	-	-	-	-	-	-	-	-
2020	-	-	-	-	-	-	-	-	-
2021	-	-	-	-	-	-	-	-	-
2022	-	-	-	-	-	-	-	-	-

10.3389/fenvs.2025.1604533

TABLE 3 Indicator values of ecological environment in the northeast region of China from 2011 to 2022.

Time	Ecological environment governance level														
	Industrial wastewater discharge			Industrial exhaust emissions			Industrial solid waste generation			Comprehensive utilization of industrial solid waste			Volume of household waste removal		
	Heilongjiang Province	Jilin Province	Liaoning Province	Heilongjiang Province	Jilin Province	Liaoning Province	Heilongjiang Province	Jilin Province	Liaoning Province	Heilongjiang Province	Jilin Province	Liaoning Province	Heilongjiang Province	Jilin Province	Liaoning Province
2011	44,072	37,563.48	90,457.1	10,377	9,618.62	31,700.8	6,017	5,378.59	28,269.61	4,139	3,170.63	10,747.8	651	493	876
2012	58,350	44,842	87,167.5	10,445	10,316	31,916.9	6,313	4,730.89	27,279.74	4,642	3,197.5	11,861.8	710	508.6	929.9
2013	47,796	42656.03	78,285.6	10,622	9803.58	29,443.5	6,094	4,591.13	26,759.45	4,145	3,711.69	11,742.3	582	485.4	927.1
2014	41,894	42192.44	90,630.8	12,091	-	34,527.5	6,312	4,944.11	28,666.32	4,069	3,477.91	10,719.2	553	504.6	917.1
2015	36,410	38771.79	83,140.3	10,843	-	34,016.5	7,495	5,385	32,434	4,308	2,986	10,029	523	490.3	933.2
2016	23,935	19237.55	57,639.2	9599	-	32,804.3	6,940.42	4,006	22,822	3,582.09	2,234	9,363	535	534.1	933.1
2017	18,058.97	20050.89	51,284.1	10,443.87	-	50,501.9	7,069.56	6,222	23,287	3,158.53	2,691	10,556	553	495	864.5
2018	19,965.66	-	39,554.7	13,335.22	-	42,666.9	8,248.44	5,143	27,466	3,444.21	2,300	11,346	525	470.6	872.2
2019	-	-	32,799.6	-	-	43,162.9	8,754	6,222	23,287	3,883	2,691	10,556	523.6	483.1	985.4
2020	15,256.9	-	29,029.5	14,058.4	-	55,096.3	6,769.13	4,676	25,526	3,166.23	2,407	11,478	497.6	464.2	993.3
2021	17,965.42	-	30,296.5	21,701.16	-	66,370.2	8,315.93	5,022	24,610	3,609.32	2,639	13,139	521.9	469.1	1029.8
2022	12,466.29	-	60,934.99091	12,736.36	-	41,109.79091	10,118	4,820	26,372	4,110	2,609	12,177	507.9	435.7	994.4

Time	Endowment											
	Planting forest area			Forest area			Green coverage rate in built-up areas			Per capita park green space area		
	Heilongjiang Province	Jilin Province	Liaoning Province	Heilongjiang Province	Jilin Province	Liaoning Province	Heilongjiang Province	Jilin Province	Liaoning Province	Heilongjiang Province	Jilin Province	Liaoning Province
2011	124,200	139,500	265,951	1,926.97	736.57	511.98	36.3	34.2	39.8	11.5	10.53	10.56
2012	157,000	134,479	246,667	1,926.97	736.57	511.98	36	33.9	40.2	11.8	10.96	10.89
2013	124,100	163,063	239,901	1,962.13	763.87	557.31	36	31.4	40.2	12.1	11.78	11.06
2014	101,100	189,839	189,839	1,962.13	736.87	557.31	36	35.8	40.1	12.1	12.05	11.61
2015	42,000	199,851	215,277	1962.13	763.87	557.31	35.8	36.1	40.3	12	12.51	11.52
2016	978,051	157,905	142,438	1,962.13	736.87	557.31	35.5	35	36.4	11.9	13.37	11.33
2017	121,124	153,038	144,223	1,962.13	763.87	557.31	35.5	35.8	40.7	11.8	11.37	12.07
2018	121,705	122,657	167,978	1,990.46	784.87	571.83	36	37.6	39.9	12.4	13.45	12.04
2019	120,858	102,929	157,599	1,990.46	784.87	571.83	36.4	39.2	40.8	12.43	12.54	11.97
2020	135,479	123,892	158,008	1,990.46	784.87	571.83	36.9	40.4	41.7	12.77	12.94	13.4
2021	95,686	105,897	56,559	1,990.46	784.87	571.83	37.4	41.1	41.8	13.6	13.55	13.44
2022	75,470	131,037	67,403	1,990.46	784.87	571.83	38	42.7	40.9	14.04	14.45	13.39

10.3389/fenvs.2025.1604533

3 Results

3.1 Indicator and weight

The development of the forestry industry and the ecological environment interact, influence, and constrain each other, indicating a specific coupling coordination relationship. Based on the research achievements of domestic and foreign scholars, this article combines the current comprehensive evaluation index of the forestry industry and ecological environment in the northeast region of China. It constructs a coupling coordinated evaluation index system for developing the forestry industry and the ecological environment in the northeast region of China. The forestry industry includes two primary indicators, and the ecological environment includes three primary indicators. The evaluation index system is shown in Table 4.

3.2 Analysis of comprehensive evaluation results

There is some fluctuation in the comprehensive evaluation values of forestry industry development and the ecological environment in the northeast region of China from 2011 to 2022. However, the fluctuation range is insignificant, especially after 2018, when the overall trends of the two systems' comprehensive evaluation values are more similar, with Jilin Province showing the most pronounced similarity. There were relatively noticeable differences in the thorough evaluation values of the two systems in Liaoning Province in 2014–2015 and Heilongjiang and Jilin provinces in 2017. The comprehensive evaluation values in the northeast region of China are shown in Figure 2.

From Figure 2, the comprehensive evaluation values of the two systems in the three provinces of the northeast region of China do not fluctuate significantly, and the differences between the two systems are not very pronounced. In Heilongjiang Province, the comprehensive evaluation value of forestry industry development showed a continuous declining trend from 2011 to 2014, reaching its lowest point in 2014 (0.8079). From 2015 to 2017, there was an upward trend, with a more noticeable increase in 2016–2017. In 2017, it reached its highest point, showing a 3.9% increase compared to 2016 and 1.45 times the value in 2014. The comprehensive evaluation value decreased by 21.24% in 2018 compared to 2017. From 2019 to 2022, it continued to decline, with a 7.23% decrease in 2022 compared to 2019.

The ecological environment's comprehensive evaluation value showed an ascending trend from 2011 to 2012, followed by a descending trend from 2013 to 2015. It reached its highest point in 2016 (1.2126) and experienced a significant decline in 2017, reaching its lowest point (0.8931). From 2018 to 2019, it began to increase again, but the increase was relatively small. From 2020 to 2022, the trend fluctuated with periods of both increases and decreases. Jilin Province showed an upward trend from 2011 to 2012, but it could have been more pronounced. It started to decline from 2013 to 2015, with the lowest value reached in 2015 (0.9210), representing a 6.3% decrease compared to 2013. From 2016 to 2017, it began to increase again, reaching its highest point in 2017 (1.1368). The comprehensive evaluation value decreased by 11.84% in 2018 compared to 2017. After a slight increase in 2019, it showed a downward trend in 2020, followed by a continuous increase from 2021 to 2022. The ecological environment's comprehensive evaluation value ascended from 2011 to 2014 and reached its highest point in 2014 (1.0578). From 2015 to 2016, it showed a descending trend, reaching its lowest point in 2016 (0.9321). From 2017 to 2019, there was an upward trend, but the magnitude of the increase was not significant. After a slight decrease in 2020, it showed an upward trend from 2021 to 2022.

In Liaoning Province, the forestry industry development's comprehensive evaluation value showed a declining trend from 2011 to 2013, with an increase in 2014, reaching its highest value (1.3508). From 2015 to 2016, it started to decline again, reaching its lowest point in 2016 (0.8729). From 2017 to 2019, it showed an upward trend, with a 10.37% increase in 2019 compared to 2016. It began to decline again in 2020; in 2022, it decreased by 3.9% compared to 2021. The ecological environment's comprehensive evaluation value increased from 2011 to 2012, followed by a slight decrease in 2013. From 2014 to 2015, it increased again, reaching its highest point 2015 (1.0516). It reached its lowest point in 2019 (0.9481) and showed an upward trend in 2020. From 2021 to 2022, it fluctuated with minor decreases.

In summary, the difference between the comprehensive evaluation values of the forestry industry development and ecological environment systems in the northeast region of China is not very obvious, and the overall trend is similar. The years with significant changes are mainly concentrated in 2014 and 2017. The differences in changes between Heilongjiang and Jilin provinces are more similar, while the years of disagreements in Liaoning Province are relatively early. Since 2018, the comprehensive evaluation values of the two systems in the three provinces have remained stable and showed almost no significant differences in numerical values.

3.3 Analysis of coupling coordination relationship

According to the comprehensive evaluation of the development of the forestry industry and the ecological environment in the northeastern region of China from 2011 to 2022, calculations were conducted to determine the coupling coordination, degree of coupling coordination, and types of coupling coordination stages between the two. The results are shown in Table 5. Additionally, Figure 3 presents a graphical representation depicting the range of coupling coordination between the development of the forestry industry and the ecological environment in the northeastern region of China from 2011 to 2022.

According to Table 5, the coupling coordination degree between forestry industry development and the ecological environment in the northeast region of China from 2011 to 2022 shows that Heilongjiang and Jilin provinces have coupling coordination degrees ranging from 3 to 9, indicating the absence of extreme imbalance, severe imbalance, and high-quality coordination. Liaoning Province has coupling coordination degrees ranging from 2 to 10, also indicating the absence of extreme imbalance.

In 2014, as a pilot for the "Stop Commercial Logging of Natural Forests" policy, key state-owned forest areas under the jurisdiction

TABLE 4 Evaluation index system for the coupling and coordination of forestry industry development and ecological environment in the northeast region of China.

Evaluation index	Primary indicator	Secondary indicator	Unit	Indicator direction	Weight		
					Heilongjiang Province	Jilin Province	Liaoning Province
Forestry industry development	Forestry industry structure	Proportion of the forestry primary industry	%	+	0.1822	0.1614	0.1996
		Proportion of the forestry secondary industry	%	+	0.1709	0.1986	0.1229
		Proportion of the forestry tertiary industry	%	+	0.1641	0.1398	0.1769
		Ratio of the total forestry output value to GDP	%	+	0.1749	0.1679	0.1518
	Forestry investment and economic construction	Investment in forestry industry development	Ten thousand yuan	+	0.1064	0.1059	0.1090
		Forestry support and guarantee investment amount	Ten thousand yuan	+	0.0967	0.1156	0.1251
		Investment in forestry infrastructure construction	Ten thousand yuan	+	0.1047	0.1108	0.1148
Ecological environment	Ecological environment pressure	Industrial wastewater discharge	10,000 tons	-	0.0863	0.0980	0.0944
		Industrial exhaust emissions	Billion cubic meters	-	0.0869	0.1381	0.0812
		Industrial solid waste generation	10,000 tons	-	0.1042	0.1013	0.1042
	Endowment	Planting forest area	Hectare	+	0.0641	0.0861	0.0875
		Forest area	10,000 ha	+	0.1548	0.1441	0.1411
		Green coverage rate in built-up areas	%	+	0.1451	0.1101	0.1377
		Per capita park green space area	Square meter	+	0.1279	0.1094	0.1195
	Ecological environment governance level	Comprehensive utilization of industrial solid waste	10,000 tons	+	0.1195	0.0920	0.1105
		Domestic waste clearance volume	10,000 tons	+	0.1112	0.1209	0.1237

of Heilongjiang Province prohibited commercial logging of natural forests, reducing exploitable resources and hindering the development of the forestry industry. The protective policies for natural forests restrained the forestry industry's development.

In 2015, Jilin and Changbai Mountain Forest Industry Group also ceased commercial timber logging. Therefore, regarding the coupling coordination relationship between the two systems, Heilongjiang and Jilin provinces experienced varying degrees of decline between 2014 and 2016.

In 2014, Heilongjiang Province had the lowest coordination level, indicating moderate imbalance, while Jilin Province had the lowest in 2016, also indicating moderate imbalance. Although Liaoning Province does not include state-owned forest areas and was not affected by the "Stop Commercial Logging of Natural Forests" policy, it had the lowest coordination level in 2016, reaching a state of imbalance.

The coupling coordination degree indicates that the coupling coordination degree of Heilongjiang Province gradually increased in 2016, reaching a state of good coordination. In 2017, the coupling coordination degrees of Jilin and Liaoning provinces increased, reaching intermediate coordination and being on the verge of imbalance, respectively. It indicates that after implementing the "Stop Commercial Logging of Natural Forests" policy, the disharmony between the two systems will be improved, and the

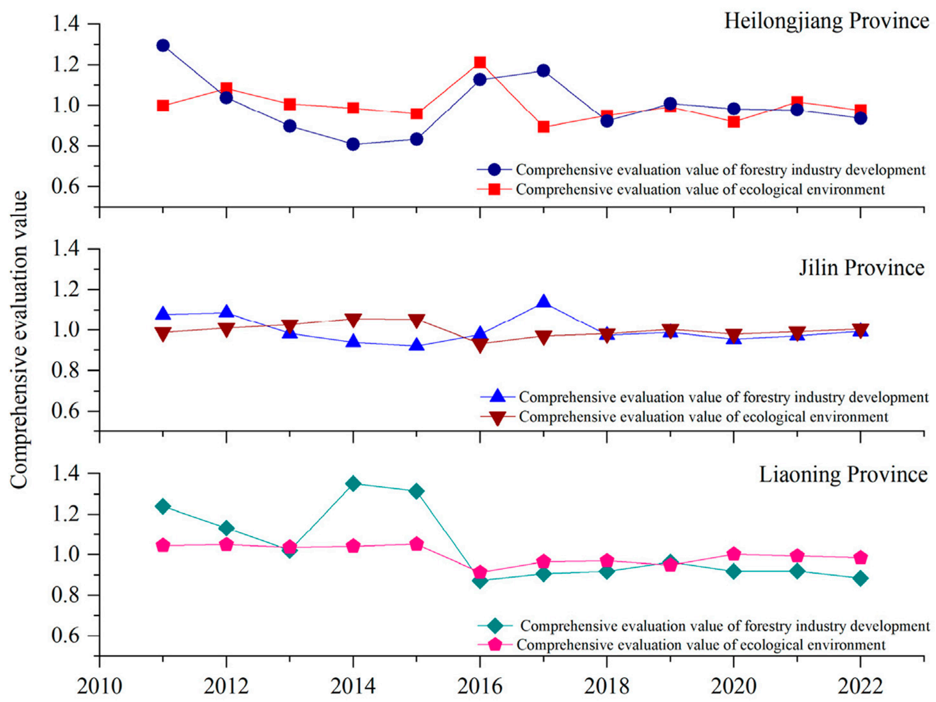

FIGURE 2
Comprehensive evaluation values of forestry industry development and the ecological environment in the northeast region of China from 2011 to 2022.

effects of the forestry industry transformation and industrial restructuring will become apparent.

However, as the forestry industry's structural adjustment is gradual, innovative industry transformation models can only be achieved after some time, leading to a rebound between the two systems. It is particularly evident in the Heilongjiang Province, which experienced a moderate imbalance in 2017, while the Jilin Province experienced a lower rebound and reached a barely coordinated state in 2018. As the forestry industry transformation and structural adjustments continue, with the primary forestry industry gaining prominence and the secondary sector experiencing a decline, the forestry industry's economic contribution will correspondingly decrease, leading to a decline in the vitality of forestry economic development.

In 2018, although afforestation and forest area increased, industrial waste emissions also increased, impacting the ecological environment's value while economic vitality declined. Between 2019 and 2022, the coupling coordination relationship between forestry industry development and the environmental climate in Heilongjiang and Jilin provinces fluctuated between coordination and imbalance.

Table 5 shows the similarity in coupling coordination degrees between the development of the forestry industry and the ecological environment in Heilongjiang and Jilin provinces in the northeast region of China from 2011 to 2022, ranging from 3 to 9, with a significant difference between years. However, extreme imbalance, severe imbalance, and high-quality coordination states are not present, and the only difference lies in the years when the coupling coordination degrees change.

The coupling coordination degree of Liaoning Province differs significantly, ranging from 2 to 10, with a broader range. Extreme imbalance is not present, but there is a severe imbalance in the state, particularly in 2016, with the lowest coupling coordination level among the three provinces. The difference in the degree of coupling coordination in Heilongjiang Province was significant in 2014 and 2016, with a level change from 3 to 9.

Jilin Province has a noticeable difference in the coupling coordination degree in 2016 and 2017, changing from 3 to 8. Liaoning Province shows a significant difference in the degree of coupling coordination in 2015 and 2016, varying from 10 to 2. The Phase II Natural Forest Protection Project was implemented in 2011, under the premise of the first phase, to continuously improve the ecological environment, protect natural forest resources and biodiversity, and play an essential role in promoting the sustainable development of forestry.

The forest resources in the northeast region of China are abundant, especially in Heilongjiang and Jilin provinces, which have abundant natural forest resources. These resources play an indispensable role in regulating the ecological environment and promoting social and economic development. Under the implementation of Natural Forest Protection Projects, the problem of forest resource shortage can be effectively alleviated, forest resource protection can be strengthened, forest resource management concepts and directions can be adjusted, and sustainable forestry development in the northeast region of China can be promoted. The afforestation and forest areas continued to increase, augmenting the ecological worth of forest resources. Although the emission of industrial waste increased, it did not

TABLE 5 Calculation results of the coupling coordination between forestry industry development and ecological environment in the northeast region of China from 2011 to 2022.

Region	Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Heilongjiang	Coupling degree C value	0.87	0.993	0.951	0.353	0.824	0.979	0.229	0.991	0.992	0.795	0.999	1
	Coordination index T-value	0.663	0.537	0.275	0.155	0.135	0.821	0.375	0.212	0.368	0.225	0.37	0.267
	Coupling coordination degree D value	0.76	0.73	0.511	0.234	0.334	0.896	0.293	0.458	0.604	0.423	0.608	0.516
	Coordination level	8	8	6	3	4	9	3	5	7	5	7	6
	Coupling coordination degree	Intermediate coordination	Intermediate coordination	Barely coordinate	Intermediate coordination	Mild dysregulation	Good coordination	Intermediate coordination	Near dysfunction	Primary coordination	Near dysfunction	Primary coordination	Barely coordinate
	Type of coupling coordination stage	Coupling state	Coupling state	Running in state	Antagonistic state	Antagonistic state	Coordination state	Antagonistic state	Running in state	Coupling state	Running in state	Coupling state	Running in state
Jilin	Coupling degree C value	0.973	0.995	0.898	0.551	0.202	0.373	0.852	0.976	0.956	0.914	0.945	0.963
	Coordination index T-value	0.583	0.689	0.52	0.54	0.483	0.139	0.65	0.325	0.44	0.266	0.354	0.459
	Coupling coordination degree D value	0.753	0.828	0.683	0.546	0.313	0.227	0.744	0.563	0.649	0.493	0.579	0.665
	Coordination level	8	9	7	6	4	3	8	6	7	5	6	7
	Coupling coordination degree	Intermediate coordination	Good coordination	Primary coordination	Barely coordinate	Mild dysregulation	Intermediate coordination	Intermediate coordination	Barely coordinate	Primary coordination	Near dysfunction	Barely coordinate	Primary coordination
	Type of coupling coordination stage	Coupling state	Coordination state	Coupling state	Running in state	Antagonistic state	Antagonistic state	Coupling state	Running in state	Coupling state	Running in state	Running in state	Coupling state
Liaoning	Coupling degree C value	0.994	0.958	0.88	0.999	0.999	1	0.749	0.795	0.99	0.688	0.723	0.468
	Coordination index T-value	0.851	0.756	0.599	0.954	0.953	0.01	0.23	0.258	0.228	0.373	0.342	0.278
		0.92	0.851	0.726	0.976	0.976	0.1	0.415	0.452	0.475	0.506	0.497	0.361

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TABLE 5 (*Continued*) Calculation results of the coupling coordination between forestry industry development and ecological environment in the northeast region of China from 2011 to 2022.

Region	Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	Coupling coordination degree D value												
	Coordination level	10	9	8	10	10	2	5	5	5	6	5	4
	Coupling coordination degree	High-quality coordination	Good coordination	Intermediate coordination	High-quality coordination	High-quality coordination	Severe imbalance	Near dysfunction	Near dysfunction	Near dysfunction	Barely coordinate	Near dysfunction	Mild dysregulation
	Type of coupling coordination stage	Coordination state	Coordination state	Coupling state	Coordination state	Coordination state	Imbalanced state	Running in state	Running in state	Running in state	Running in state	Running in state	Antagonistic state

seriously impact the ecological environment in the northeast region of China.

The coupling coordination relationship in the three provinces of the northeast region is at an intermediate coordination level or higher. In 2014, Heilongjiang and Jilin provinces embarked upon a new era of safeguarding natural forest resources due to the "Stop Commercial Logging of Natural Forests" policy, which completely halted commercial logging of natural forests. Implementing this policy has led to a decrease in exploitable resources in the two provinces, which significantly impacts the development of the forestry industry and indirectly reduces the economic vitality of forestry.

Therefore, there has been a varying degree of decline in the coupling coordination between the development of the agricultural sector and the ecological environment in Heilongjiang and Jilin provinces. Implementing the "Stop Commercial Logging of Natural Forests" policy should fully leverage the environmental benefits of forest resources and attach more importance to the ecological efficacy of forests, which has a more significant impact on the development of the forestry industry. Although Liaoning Province's forest resources mainly consist of ecological public welfare forests, which play a crucial role in improving the ecological environment and promoting sustainable economic development, the "Stop commercial Logging of Natural Forests" policy did not affect the province.

From 2011 to 2015, the coupling coordination between the two systems in Liaoning Province was at an intermediate or higher coordination level. For many years, it was in a state of high-quality coordination. In confronting the resource challenges presented by forestry development, Heilongjiang and Jilin provinces are recalibrating their forestry industrial framework and seeking transformative paradigms. These efforts are intended to ease the strained dynamics between forest resource sustainability and forestry development. The goal is to find a harmonious equilibrium that facilitates coordinated advancement, safeguarding the ecological environment while fostering the sustainable growth of the forestry sector. Various measures have been proposed to promote the development of the forestry industry, focusing on low-carbon, green, and circular industries under the premise of ecological protection to reduce the environmental impact of forestry industry development.

In 2016, the emission of industrial waste in Heilongjiang Province decreased, effectively harnessing the ecological functionality and value of the ecological environment by reducing environmental damage. Nevertheless, due to the sluggish and inefficient progress in the transformation and structural adjustment of the forestry industry, its economic contribution has dwindled, resulting in a waning vitality. Although afforestation and forest area increased in 2018, the emissions from industrial waste also increased, impacting the value of the ecological environment while economic vitality declined.

Between 2019 and 2022, the coupling coordination relationship between the two systems in Heilongjiang and Jilin provinces shifted between coordination and imbalance. In 2021, the first year of the "14th Five-Year Plan," the primary focus of ecological and environmental planning was to strictly adhere to ecological protection redlines, explore novel mechanisms for industrial

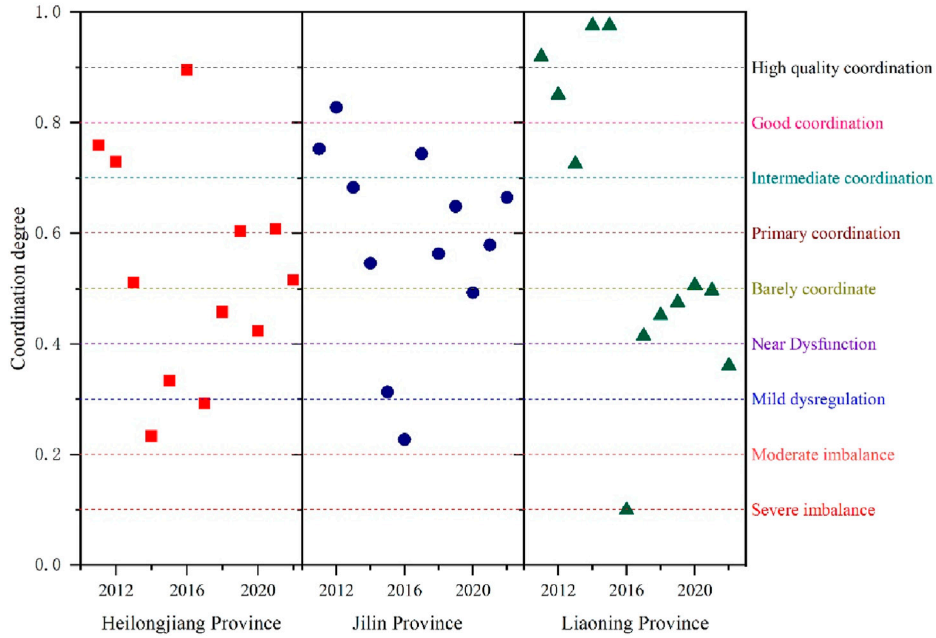

FIGURE 3
Coupling coordination interval of forestry industry development and the ecological environment in the northeast region of China from 2011 to 2022.

environmental access, enhance the regional ecological environment governance system, modernize its capacities, and promote green, high-quality development. The "14th Five-Year Plan" has brought about a continuous adjustment and transformation in the coupling coordination between the two systems in the northeast region of China.

According to the coupling coordination degree, the current coupling coordination status between forestry industry development and the ecological environment in Heilongjiang and Jilin provinces in the northeast region of China can be classified into four categories, namely, antagonistic, transitional, coupled, and coordinated states, without any imbalance states. The coupling coordination status between the two systems in Liaoning Province includes coordinated and imbalanced states.

From Figure 3, it can be observed that the distribution of the coupling coordination degree between forestry industry development and the ecological environment in the northeast region of China from 2011 to 2022 is as follows: Heilongjiang and Jilin provinces show consistent distributions, without any imbalance states, and they are mainly distributed between 3 and 9. Liaoning Province exhibits a more scattered distribution, primarily divided into three ranges: the upper range indicates a coordinated state, the middle range represents a transitional state, and the lower range indicates an imbalance state. The overall distribution includes all levels, which differs significantly between Heilongjiang and Jilin provinces.

The graph shows that the coupling coordination status between the two systems in Heilongjiang and Jilin provinces in the northeast region of China from 2011 to 2022 has a relatively even distribution. Still, there is a significant difference in the overall range of the coupling coordination degree, with variations among different years. It can be attributed to adjustments in forestry industry development policies and measures focused on ecological and environmental protection, particularly the impact of the Natural Forest Protection Project and the "Stop Commercial Logging of Natural Forests" policy on the environment. These initiatives have led to a new era of comprehensive protection of forest resources in both provinces, focusing on ecological construction and fully leveraging the environmental value of forest resources.

On the other hand, besides being influenced by the Natural Forest Protection Project, Liaoning Province has not been subject to the "Stop Commercial Logging of Natural Forests" policy, resulting in its overall placement in a coordinated and coupled state from 2011 to 2015. The differences in the coupling coordination relationship between the two systems in the three provinces can also be attributed to the continuous adjustments and upgrades in the forestry industry structure and the transformation toward a low-carbon and green forestry industry. In summary, a particular gap exists between the coupling coordination level between the forestry industry development and the ecological environment in the northeast region of China and the ideal state of coordinated development.

4 Discussion

This article applies a coupling coordination model to calculate the coupling coordination relationship between the development of the forestry industry and the ecological environment in the northeast region of China from 2011 to 2022. Most scholars measure the relationship between financial development, social development, terrestrial ecosystems, and the environment in different regions or systems (Hu et al., 2023). Jingfeng et al. (2018) analyzed the relationship between the regional economy and the environmental system by constructing a coupling model that balances the relationship between the government and relevant departments. Ma et al. (2013) constructed a regional economic construction and environmental pollution evaluation index system to calculate the coupling coordination of regional economic and ecological systems. However, it mainly focuses on industries such as manufacturing, processing, coal, and building materials (Ma et al., 2013) and does not include the forestry industry. Some scholars have also applied the VAR model to analyze the dynamic effect relationship between economic growth and environmental quality (Zhao and Han, 2019). Although there are many methods to measure the relationships between different systems and calculate based on other regions, various choices of evaluation indicators can lead to different results. Therefore, selecting indicators is particularly important for coupling coordination. Most scholars choose positive indicators when calculating the relationship between the economy and the environment unless they calculate the relationship between economic development and environmental pollution (Liu et al., 2023). To more accurately reflect the coupling coordination relationship between forestry industry development and the ecological environment, this article constructs a bidirectional indicator system to ensure the accuracy of the calculation results. This relationship will be beneficial for promoting high-quality economic growth in Northeast China and achieving sustainable forestry development.

The ecological environment in Northeast China is superior, with abundant forest resources, mineral resources, grasslands, and wetland resources. However, the abundance of resources can also lead to resource constraints. The excessive consumption of resources not only tends to create a relatively single industry structure but also causes environmental damage, resulting in an imbalance between economic development and ecological protection. The contradiction between the forestry industry and the ecological environment is particularly prominent. Due to adjustments and changes in national forestry policies, the coupling relationship between the two systems has shown different coupling coordination states at various stages. Therefore, this article takes the northeast region of China as an example to analyze and calculate the coupling coordination relationship between forestry industry development and the ecological environment, which has specific practical significance.

The research shows that the degree of coupling coordination between the two systems in the northeast region of China from 2011 to 2022 varied widely. Heilongjiang and Jilin provinces range between 3 and 9, while Liaoning Province ranges between 2 and 10, with variations among different years. Due to the adjustment and improvement of forestry and forestry industry-related policies and the effective implementation of ecological and environmental protection measures, the northeast region of China has actively adjusted and upgraded its forestry industry structure to promote high-quality and green development.

As a substantial industrial base, the northeast region of China made historic and outstanding contributions to economic development at the beginning of the founding of the People's Republic of China. With the continuous development of the economy, the northeast region of China has formed an industrial advantage dominated by resource development, which, in turn, promotes the economic development of the northeast region of China. Forestry development made the Northeast China a significant timber supply base for the country.

However, the continuous consumption of natural forest resources led to environmental deterioration. In response, the Central Committee and the State Council made important decisions to implement the Natural Forest Protection Project. The project, officially implemented in 2000, fundamentally curbed environmental degradation and promoted sustainable socio-economic development. Due to the implementation of the first phase of the Natural Forest Protection Project and its significant results, the second phase began in 2011. With the continuous implementation of the second phase of the Natural Forest Protection Project, natural forest resources have been classified and adjusted, and zoning management has been carried out according to resource types.

At the same time, the management methods and concepts of forest resources have also been adjusted. The "National Forestry Bureau's Outline for Promoting Ecological Civilization Construction Plan (2013–2020)" set clear boundaries for ecological protection and regulated the systematic construction of the environmental cultural system. In 2021, as the first year of the "14th Five-Year Plan," the primary focus of ecological and environmental planning is to strictly adhere to ecological protection redlines, explore new mechanisms for industrial environmental access, and enhance the modernization of regional, ecological, and environmental governance systems and capabilities. However, without industrial support, the vitality of environmental construction will be lost. Therefore, the development of the forestry industry and the protection of the ecological environment mutually support and promote each other.

With the introduction of a national low-carbon economy, green circular development, and clean production concepts, the development of the forestry industry must prioritize ecological protection and actively seek a path of low-carbon, green, and sustainable development. Therefore, as related policies change, they inevitably impact the safety of the ecological environment in the northeast region and the development of the forestry industry. By analyzing the coupling coordination relationship between the two, the study shows the development process from coordination to imbalance and then back to coordination. It also reveals the broad scope of the coupling coordination relationship and the specific differences between the two systems.

5 Policy recommendations and conclusions

5.1 Policy recommendations

(1) The transformation model of the forestry industry must be optimized. The northeast region of China has abundant forest resources, but its economic development is relatively backward. Promoting economic growth based on fully tapping into the ecological value of resources is the key to the comprehensive revitalization of the northeast region of China. The northeast region of China aims to optimize the transformation model of the forestry industry, improve the current status of forest resources, fully utilize regional resource advantages, and promote sustainable economic

development while protecting the ecological environment. The northeast region of China can further promote the development of the forestry industry through models such as green industry, low-carbon circular industry, and digital industry, thereby effectively promoting the coordinated development of the forestry industry economy and ecological environment in the northeast region of China.

(2) Advantageous resources must be fully and reasonably utilized. The proposal of the Northeast Revitalization Strategy focuses on the economic development of the northeast region of China. It fully leverages the critical role of the ecological barrier in the northeast region of China. The agriculture and forestry in Northeast China are relatively developed, serving as the natural foundation of a comprehensive agricultural base and an essential ecological barrier in northern China. The northeast region of China aims to achieve comprehensive revitalization by fully and reasonably utilizing advantageous resources, effectively developing and utilizing them, and generating a moderate economic scale.

(3) Clean production projects must be strongly advocated. To protect the ecological environment, the northeast region of China should strive to minimize waste discharge into the external environment through clean production in all industrial projects under environmental constraints, especially in the forestry industry. We should promote the clean transformation of the forestry industry while protecting the environment.

(4) The development of the low-carbon economy must be promoted. Forest resources, afforestation, and nurturing management will all become important ways to reduce carbon emissions. As an essential carbon sink resource, forest resources can bring specific economic value while protecting the environment. The northeast region of China can rely on abundant forest resources to promote the regional economy and sustainable development of resources by developing low-carbon and carbon-sink economies.

The research in this article shows that although the coupling coordination relationship between the development of the forestry industry and the ecological environment in Northeast China from 2011 to 2022 can be described, there are still certain shortcomings. The selection of evaluation indicators and research methods for developing the forestry industry and ecological environment may have specific limitations due to external factors, leading to biased research results. In addition, due to the author's limited ability and practical experience, this study may also need to be revised. There will be more progress through continuous learning and field investigation. In future research, more attention should be paid to the specific influencing factors of the relationship between the forestry industry and the ecological environment and the obstacles that hinder their healthy development.

5.2 Conclusion

The coupling coordination between forestry industry development and the ecological environment in Northeast China has not yet reached a good coordination state. The coupling coordination degrees of Heilongjiang, Jilin, and Liaoning provinces vary widely, ranging from 3 to 9 in Heilongjiang and Jilin provinces and from 2 to 10 in Liaoning Province, covering almost all levels, and there is a particular gap between the data for each year. The status of the coupling coordination of Liaoning Province includes all states. In contrast, the Heilongjiang and Jilin provinces include antagonistic, adaptive, coupling, and coordination states, and there has not been any imbalance yet.

From the abovementioned findings, the development of the forestry industry and the ecological environment in Northeast China promote and constrain each other, and the research results will reflect the coupling coordination relationship between the two systems. The development of the forestry industry and ecological environment in Northeast China has not yet reached a good coordination state, which will provide a specific practical basis for formulating forestry industry policies and ecological environment protection policies. At the same time, promoting the benign coordination between the two will also become the main direction for the future development of the forestry industry and ecological construction in Northeast China.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material; further inquiries can be directed to the corresponding author.

Author contributions

QZ: funding acquisition, conceptualization, and writing – original draft. DB: formal analysis, methodology, and writing – review and editing. CK: funding acquisition, project administration, and writing – review and editing. WG: resources, software, and writing – original draft.

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Conflict of interest

Author WG was employed by Daqing Huali Biotechnology Co., Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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